Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 111 (2015) 797 – 802

Procedia Engineering

www.elsevier.com/locate/procedia

XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP) (TFoCE 2015)

Influence of surface emissivity on the heat loss through the wall behind the heater

Nina P. Umnyakova[a]*

[a]*Department of Structural Mechanics, Moscow State University of Civil Engineering (MGSU), 26 Yaroslavskoe chaussee, Moscow, 129337, Russian Federation*

Abstract

The paper presents a solution to a problem of heat transfer through the external wall region behind the heater, which is actively warming up and through which additional heat loses occur. Author developed a method for temperature calculations on the inner surface of the external wall region behind the heater, that takes into account inner wall surface material reflection coefficient. According to the author's conducted calculations it is possible to show, that due to application of a baffle, made of aluminum foil with low emission coefficient, temperature of the wall surface behind the heater declines as well as the heat loses through this part of the wall. Calculations made by proposed method allows us to estimate efficiency of materials with low surface emission coefficient application in the exterior walls.

Peer-review under responsibility of organizing committee of the XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP)

Keywords: Reflective insulation; Emissivity coefficient; Thermal resistance; Heat transfer; Radiation; Reflection; Convection; Heat conductivity.

1. Introduction

Building heating system is designed for creating comfortable thermal conditions for inhabitants and the heating appliance is the main element that facilitates the income of necessary amount of heat inside the building. Typically, heating appliances are located near external wall surface under the window. According to Russian Federation codes, the length of the heater should be not less than ¾ of daylight width.

* Corresponding author. Tel.: +7-915-023-03-85; fax: +7-495-482-4060.
E-mail address: n.umniakova@mail.ru

1877-7058
Peer-review under responsibility of organizing committee of the XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP)
doi:10.1016/j.proeng.2015.07.148

Nomenclature

C_h	emission coefficient of heater surface, $W/m^{2\,0}C^4$
τ_h	temperature of heater surface, ^0C
C_{hw}	emission coefficient of inner surface of external wall behind the heater, $W/m^{2\,0}C^4$
τ_{hw}	temperature of inner surface of external wall behind the heater, ^oC
C_o	black body emission coefficient, $W/m^{2\,0}C^4$
K	heat transfer ratio of external wall, $W/m^{2\,0}C$
R_c	thermal resistivity of external wall, $m^{2\,0}C/W$
R_{ext}	heat exchange resistance near external wall surface, $m^{2\,0}C/W$
α_{rad}	radiation heat transfer coefficient, $W/m^{2\,0}C$

Surface temperature of the heater located near the external wall is higher than the temperature of the inner air, so the room heating is accomplished through thermal dissipation by means of convection and radiation. Generally, the radiative heat flow from the heater spreads in all directions, warming up not only the room's interior, but also the external wall surface behind the heater. As a result of more intensive heat penetration through the wall behind the heater, total heat loses increases compared with heat loses through the ordinary (without the heater) wall region, which are not accounted for in aggregated building heat loss calculations [1,2]. Moreover, the warm up process of the interior wall surface arises mainly by means of radiative heat transfer from the heater. However, it is possible to decrease the inner wall surface temperature via application of a baffle made of reflective insulation materials, e.g. aluminum foil. Still, there are no methods to estimate efficiency of radiative insulation application [3,4,5].

In this respect, we stated a problem of determination the amount of heat that is lost through the wall behind the heater.

2. Method description

Consider that the surface area of the wall behind the heater F_{hw} is 10% larger than the heat-release surface of the heating appliance F_h, so F_{hw} =1,1F_h.

The air cavity thickness between the heater's surface and the wall behind it is small and the product of Grasgov's criteria on Prandtl's criteria $Gr \cdot \Pr < 1000$. According to these assumptions, we can easily ignore the convection component of heat transfer. The thermal conductivity part of heat transfer process is also ignored because the air cavity is not closed. That is why the heat transfer between these two surfaces will be due to radiative heat exchange [6, 7].

The amount of heat, flows from the heat appliance to the wall surface behind it will be:

$$Q_h^{flow1} = \frac{C_h C_{hw}}{C_o}\left[(\frac{\tau_h + 273}{100})^4 - (\frac{\tau_{hw} + 273}{100})^4 \right] F_h \tag{1}$$

or

$$Q_h^{flow1} = \frac{C_h C_{hw}}{C_o C_{red}}\left[(\tau_h - \tau_{hw}) \right] F_h \tag{2}$$

The amount of heat, reflected form the wall surface behind the heater backward to it will be calculated as follows:

$$Q_{hw}^{refl} = \frac{C_{hw} C_h}{C_o}\left[(\frac{\tau_{hw} + 273}{100})^4 - (\frac{\tau_h + 273}{100})^4 \right] (1 - \frac{C_{hw}}{C_o}) F_{hw} \tag{3}$$

or

$$Q_{hw}^{refl} = \alpha_{rad} \frac{C_{hw} C_h}{C_{red} C_o} \left[(\tau_{hw} - \tau_h) \right] . (1 - \frac{C_{hw}}{C_o}) F_{hw} \tag{4}$$

The amount of heat flowing through the external wall behind the heater due to the temperature difference between the wall τ_{hw} and the external air t_{ext}, satisfy the equation:

$$Q_{hw} = K(\tau_{hw} - t_{ext}) F_{hw} \tag{5}$$

where $K = 1/(R_c + R_{ext})$.

Therefore, the amount of heat that flows through the external wall region behind the heater with area of F_{hw} from the heating appliance F_h, according to the heat balance law satisfy the equation:

$$Q_{hw} = Q_h^{flow1} - Q_{hw}^{refl} \tag{6}$$

Substituting Eq. (1) – (5) in balance equation (6) we'll get expanded balance equation, that has a form:

$$K(\tau_{hw} - t_{ext}) F_{hw} = \alpha_{rad} \frac{C_{hw} C_h}{C_{red} C_o} (\tau_h - \tau_{hw}) - \alpha_{rad} \frac{C_{hw} C_h}{C_{red} C_o} (\tau_{hw} - \tau_h)(1 - \frac{C_{hw}}{C_o}) F_{hw} \tag{7}$$

After transformations of Eq. (7), we'll get an equation to derive temperature values on the wall surface behind the heater versus heater temperature, heat insulating capabilities of external wall and exterior air temperature:

$$\tau_{hw} = \frac{\alpha_{rad} \frac{C_{hw} C_h}{C_{red} C_o} \left[F_h + (1 - \frac{C_{hw}}{C_o}) F_{hw} \right] + K t_{ext} F_{hw}}{\alpha_{rad} \frac{C_{hw} C_h}{C_{red} C_o} \left[F_h + (1 - \frac{C_{hw}}{C_o}) F_{hw} \right] + K F_{hw}} \tag{8}$$

Surface radiative heat exchange coefficient is defined according to reduced emission coefficient C_{red} and temperature coefficient Ω [8].

In order to find surface temperature of external wall behind the heater we apply a formula, that is conventionally used in calculations and not accounting on surface wall emission coefficient [7 – 9]:

$$\tau_{ext} = t_{ext} + \frac{\tau_{hw} - t_{ext}}{R_{hw}} R_{ext} \tag{9}$$

3. Method application

We examine temperature difference and amount of heat loses inside external wall behind the heater with and without the baffle made of aluminum foil placed on internal surface of exterior wall. Let us assume the emission coefficient of heater surface C_h = 4,9 W/m^2 ^{0}C^4, emission coefficient of plaster mortar C_{hw} = 4,6 W/m^2 ^{0}C^4, emission coefficient of reflective insulation made of aluminum foil $C_{al.f}$ = 0,5 W/m^2 ^{0}C^4, black body emission coefficient C_0 = 5,76 W/m^2 ^{0}C^4.

Reduced emission coefficient is derived from equation:

$$C_{red} = \frac{1}{\frac{1}{C_h} + \frac{1}{C_{hw}} - \frac{1}{C_o}} \tag{10}$$

Due to radiative heat exchange between the surface of air cavity with emission coefficient C_h = 4,9 W/m^2 ^{0}C^4 и C_{hw} = 4,6 W/m^2 ^{0}C^4, the reduced emission coefficient according to Eq. (10) equals to C_{red} = 4,03 W/m^2 ^{0}C^4; for surfaces with parameters C_h = 4,9 W/m^2 ^{0}C^4 и $C_{al.f}$ = 0,5 W/m^2 ^{0}C^4, the reduced emission coefficient according to Eq. (10) equals to C_{red} =0,86 W/m^2 ^{0}C^4.

Radiation heat transfer coefficient between the heater surface and the wall's surface behind it without the aluminum foil baffle will be calculated as follows:

$$\alpha_{rad} = \frac{1}{\frac{1}{4,6} + \frac{1}{4,9} - \frac{1}{5,76}} = 1,42 \ = \ 5,72 \ W / m^2 \, {}^0C^4 \tag{11}$$

Radiation heat transfer coefficient between the heater surface and the reflective baffle made of aluminum foil placed on inner surface of external wall behind the heater will be:

$$\alpha_{rad} = \frac{1}{\frac{1}{0,5} + \frac{1}{4,9} - \frac{1}{5,76}} = 1,35 \ = \ 0,66 \ W / m^2 \, {}^0C^4 \tag{12}$$

Consider that one section of external heating surface is 0,465 m^2. Standard heating appliance is placed under the window consisting of 6 sections, so the total external heating surface will be 0,465 x 6 = 2,79 m^2. The surface area of the heating appliance facing the external wall surface equals to 1/3 of the total heater's surface. Then, the heater's surface area equals F_h = 2,79 x 1/3 = 0,93 m^2. The wall surface, that is warmed up by the heater, is increased 10%, than it's area will be F_{hw} = 9,3 x 1,1 = 1,02 m^2.

Figure 1 shows the temperature pattern inside the external wall behind the heater (Fig. 1a) and without the heater (Fig. 1b) due to regulated temperature drop of 69,5 ^{0}C, exterior air temperature -26 ^{0}C and interior air temperature +20 ^{0}C. It can be easily seen, that without the reflective baffle, the exterior wall surface temperature is 51,38 ^{0}C. The application of a reflective baffle, made of aluminium foil, allows for decreasing of wall's surface temperature up to 13,5 ^{0}C due to reflection of heat transfer back inside the room. Moreover, the heat loses through this part of the wall decrease by a factor of two.

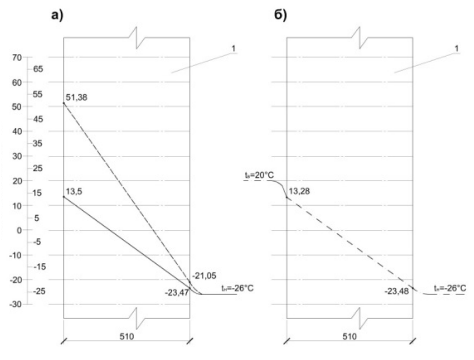

Fig. 1. Temperature pattern iside the wall (a) behind the radiator; (b) through expanse of wall. Outside air temperature -26 ^{0}C, inside air temperature +20 ^{0}C. - - - - – without reflective baffle; ---- – with reflective baffle.

Performed finite-element modelling of wall's region behind the heater allows us to get a 3-D temperature distribution field both on the inner surface of external wall behind the heater and inside it while applying or not of reflective baffle made of aluminium foil. Figures 2 and 3 shows the 3-D temperature distribution fields in the wall region with applied or absent reflective baffle made of aluminium foil.

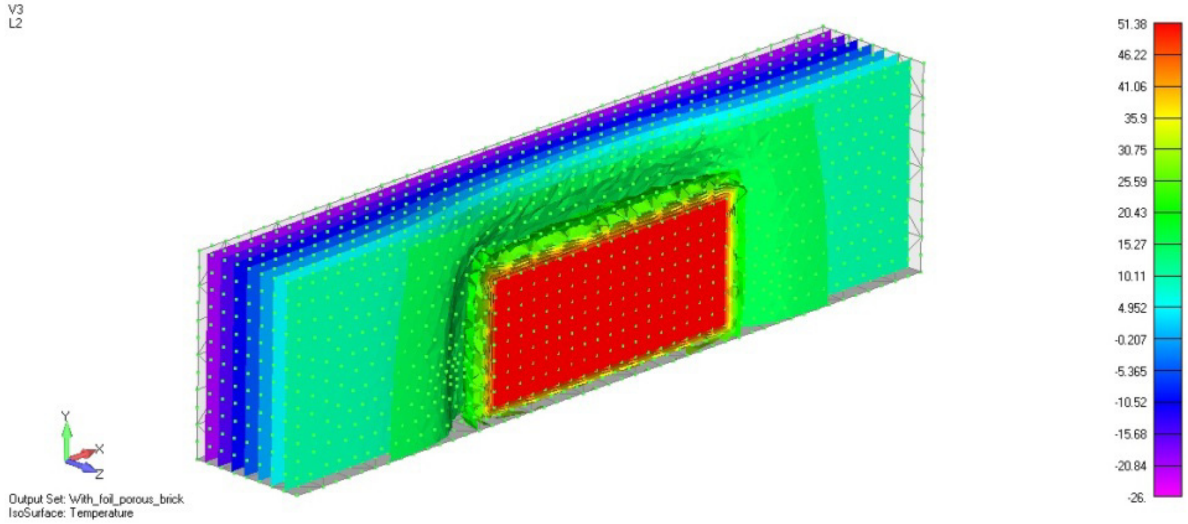

Fig. 2. 3-D temperature distribution field in the wall region behind the heater without reflective baffle. Outside air temperature -26 ^{0}C, inside air temperature +20 ^{0}C.

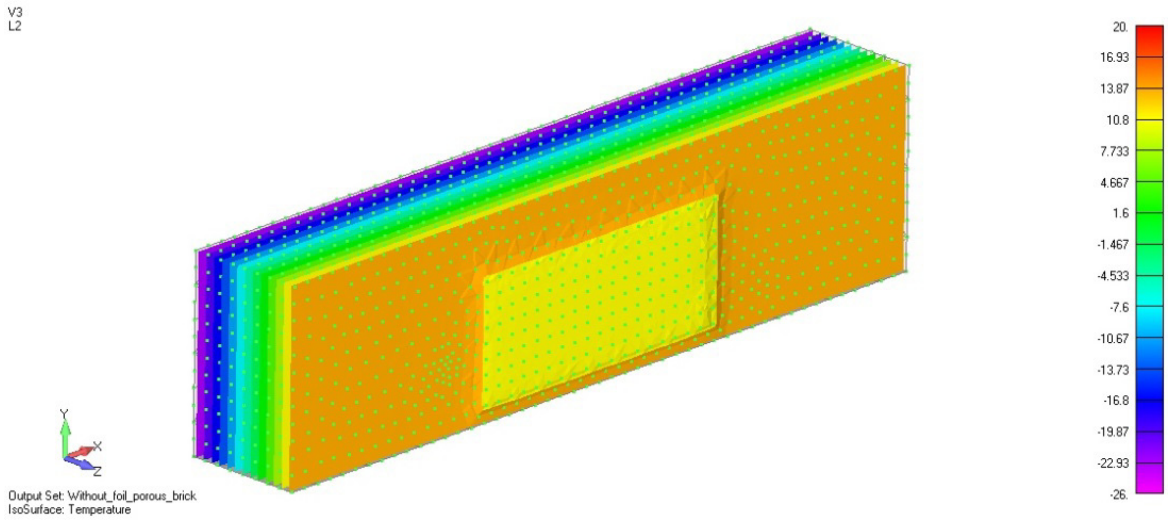

Fig. 3. 3-D temperature distribution field in the wall region behind the heater with applied reflective baffle. Outside air temperature -26 ^{0}C, inside air temperature +20 ^{0}C.

4. Conclusion

Proposed method for temperature calculations on the exterior wall inner surface behind the heating appliance allows to account for its reflection coefficient. The results of calculations, performed by this method, brings an opportunity to assay the effectivity of material application with low emission coefficient and theirs influence on total heat loses in buildings.

References

[1] GOST R 54853-2011 Building and structures. A method of determination of resistance to a heat transfer of the protecting designs by means of the heat meter [GOST P 54853-2011. Zdaniya i sooruzheniya. Metod opredeleniya soprotivleniya teploperedache ograzhdayushchikh konstruktsii s pomoshch'yu teplomera.]. Moscow: Standartinform. 2012.

[2] K. F. Fokin, Construction heat engeneering of building envelope. Moscow, 2006, 256 pp.

[3] I. Ya. Kiselev, Rational design by means of the solution of questions of construction physics. Glasing and Building Constructions. 2009. No 6, pp. 32 – 34. (In Russian).

[4] N. P. Umnyakova, I. N. Butovskii, A. G. Chebotarev, Development of methods of rationing of a heat-shielding of power effective buildings. Civil Engeneering (Zhilishchnoe stroitel'stvo*)*. 2014. No 7, pp. 19-23. (In Russian).

[5] N. P. Umnyakova, K. S. Andreitseva, V. A. Smirnov, Effective solution of a cover of the building and biospheric compatibility. Biospheric compatibility: person, region, technologies. 2013. No 4, pp. 51-64.

[6] N. P. Umnyakova, Heat-shielding of the closed air layers with reflective thermal insulation. Civil Engeneering. (Zhilishchnoe stroitel'stvo). 2014. No 1-2, pp. 16-20.

[7] N. P. Umnyakova, Influence of coefficient of radiation the of materials with aluminum foil on a heat transfer through external protections. [Electronic document]. Science and safety. 2015. No 2. http://www/science-and-safety.rf/15-maj-2015.

[8] K. F. Fokin, Building thermophysics of building envelope. Moscow, 2006. – 256 pp.

[9] A. A. Akhremenkov, V. A. Kuzmin, A. M. Tsirlin, Energy efficiency of Coating the Inner surface of permises with reflective insulation. Construction materials , 2013. No 12, pp.65-67